


Graduate Level Modeling and Simulation Overview Course

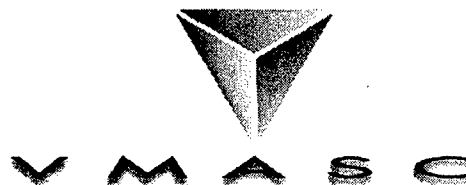
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Final Technical Report
Contract N00014-031-094S

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Graduate Level Modeling and Simulation Overview Course
Final Technical Report

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1. Purpose

This document reports the results of a project to develop and test the content of a graduate level modeling and simulation overview course.

This report was prepared for the Defense Modeling and Simulation Office (DMSO) by the Virginia Modeling, Analysis and Simulation Center of Old Dominion University, with inputs from both the University of Central Florida and the Georgia Institute of Technology. It describes work done under and is the final report for contract N00014-031-094S "Graduate Level Modeling and Simulation Overview Course". The Old Dominion University Research Foundation project number is 234921.

2. Project overview and history

Old Dominion University (ODU), the University of Central Florida (UCF), and the Georgia Institute of Technology (GT) were tasked by the Defense Modeling and Simulation Office (DMSO) to jointly develop a 40-hour course of instruction to introduce students to the overall discipline of modeling and simulation (M&S). The course was intended to be a survey, emphasizing breadth rather than depth of coverage. Course topics were to include definitions, modeling methods, simulation project life-cycle, simulation verification and validation, simulation output analysis, and many others. The expectation was that students completing the course would have an overall understanding of M&S and will be prepared to place specific M&S topics in context and study them in more detail.

In a series of face-to-face meetings and electronic exchanges, ODU, UCF, and GT jointly produced a topical outline for the M&S content required to introduce graduate students to the discipline of modeling and simulation, which became known as the M&S "Body of Knowledge", and a topic sequence for a university course based on the "Body of Knowledge".

ODU, UCF, and GT separately produced distinct portions of the course content in form of lectures slides and associated reading materials and homework assignments. The topics to be produced by each university were determined by mutual agreement among the universities.

The project initially was to include a single offering of the course as a concentrated week-long 40-hour session to a group of students selected by DMSO at a site arranged by DMSO.

However, that requirement was removed by the DMSO representative (Ms. Simone Youngblood) at the May 24-25 2004 project meeting held at GIT. His decision was based on both logistical and pedagogical considerations. Instead, the universities were asked to use the developed content in their existing M&S introductory courses and to enhance that content, and the overall M&S Body of Knowledge outline, based on that experience.

A large number of high quality M&S course content modules were developed by the universities. Those modules were used to good effect in the universities' respective Introduction to M&S regular courses. There was some sharing of course content between the universities, but perhaps not as much as originally hoped for. The course content modules have also been used as the basis for professional education courses by at least two of the universities.

3. Project objectives

The objectives of the project were changed by the sponsor during its execution. Both the original and revised objectives are listed in this section.

3.1 Original project objectives

Old Dominion University, the Georgia Institute of Technology, and the University of Central Florida (collectively, "the universities") were to design, develop, and deliver, in partnership, a Modeling and Simulation Overview course.

The original project objectives were to:

1. Determine the M&S content required to introduce graduate students to the discipline of modeling and simulation, documented in the form of a modeling and simulation "Body of Knowledge", i.e., a topical outline of the course.
2. Develop course content, at the Master's level, for those specific topics outlined in the Body of Knowledge topical outline. Specific course content was to include read-ahead materials (from textbooks and papers), lecture and lecture support materials, and an integrated set of computer-based laboratory exercises.
3. Implement a process for course content review that ensured that existing and new course content developed separately by the universities for the course was examined, and modified if necessary, for coherence and effective pedagogical structure.
4. Teach the course as a concentrated week-long 40-hour session to a group of students selected by DMSO at a site arranged by DMSO. The students were expected to be drawn from military, government civilian, and government contractor personnel transitioning to M&S related duties from other areas.
5. Prepare recommendations for course improvement and refinement in future offerings, based on experiences in teaching the course.

3.2 Revised project objectives

On May 24, 2004 the project objectives were changed by the sponsor, represented by Ms. Simone Youngblood, at the project meeting being held that date at GIT. The revised project objectives were:

1. Determine the M&S content required to introduce graduate students to the discipline of modeling and simulation, documented in the form of a modeling and simulation "Body of Knowledge", i.e., a topical outline of basic M&S knowledge.
2. Develop course content, at the Master's level, for specific topics defined in the Body of Knowledge topical outline. Specific course content was to include read-ahead materials (from textbooks and papers), lecture and lecture support materials, and an integrated set of computer-based laboratory exercises.
3. Use the content to support instruction within the existing M&S introductory courses taught at each of the three partner universities. Each university was to use all of the content it had developed as well as portions of the content developed at the other universities.
4. After using the content and observing its instructional effectiveness, either enhance it (for content developed at the using university) or provide feedback to the creating university (for content developed at the other universities).
5. Provide recommendations for revisions to the overall M&S "Body of Knowledge", the course topical outline, based on the instructional experiences.

4. Project outcomes

The outcomes of the project are listed in this section.

1. ODU, UCF, and GIT jointly determined the M&S content required to introduce graduate students to the discipline of modeling and simulation. That content was documented in the form of an M&S "Body of Knowledge" (BoK), i.e., a topical outline of basic M&S knowledge. The BoK was developed over the course of a sequence of electronic exchanges and face-to-face meetings. It was circulated among the academic M&S community; some valuable feedback resulting from this circulation was incorporated into the BoK.
See Appendix 8.1 for the final version of the BoK.
See Appendix 8.10 for a brief chronology of the project meetings.
2. ODU, UCF, and GIT jointly developed a topic sequence for a graduate level university M&S overview course. The course topic sequence was very closely based on the M&S BoK, but differs from it so as to conform to the constraints of a 1-semester university course in terms of time structure (sequence of fixed-length lectures) and time constraints (approximately 40-45 lecture hours). Responsibility for developing course content for each topic was partitioned among the universities by negotiated mutual agreement.
See Appendix 8.2 for the overview course topic sequence.
3. ODU developed a total of 22 course content teaching modules applicable to topics in the M&S BoK and the overview course topic sequence. The modules were in the form of PowerPoint lecture slides. The 22 modules together totaled approximately 1,200 slides and covered 24 topics from the M&S overview course topic sequence and 27 topics from the M&S BoK.
See Appendix 8.3 for a list of those content modules.
4. UCF developed a total of 12 course content teaching modules applicable to topics in the M&S BoK and the overview course topic sequence. The modules were in the form of PowerPoint lecture slides. The 12 modules together totaled approximately 900 slides and covered 11 topics from the M&S overview course topic sequence and 12 topics from the M&S BoK.
See Appendix 8.4 for a list of those content modules.
5. UCF assembled 5 multimedia segments of instructional value to augment the M&S overview course lectures. UCF edited and prepared them for classroom delivery.
See Appendix 8.5 for a list of those multimedia segments.
6. GIT developed a total of 3 course content teaching modules applicable to topics in the M&S BoK and the overview course topic sequence. The modules were in the form of PowerPoint lecture slides. The 3 modules together totaled approximately 300 slides and covered 3 topics from the M&S overview course topic sequence and 3 topics from the M&S BoK.
See Appendix 8.6 for a list of those content modules.
7. ODU provided a portion of its course content modules, 3 introductory lectures totaling 6 hours of instruction comprised of 153 slides, to UCF and GIT for their evaluation and possible use.
8. ODU used the course content modules prepared by ODU under the project in teaching the ODU Introduction to M&S course (MSIM 601) during the Fall 2004 semester, which ended in December 2004.
See Appendix 8.7 for the ODU Introduction to M&S topic sequence and the modules used.

9. ODU used the course content modules prepared by ODU under the project to teach several custom M&S professional education short courses; clients for courses were Booz Allen Hamilton, the Defense Threat Reduction Agency, and the National Institute for Aerospace.
10. UCF used the course content modules prepared by UCF under the project in teaching the UCF Introduction to M&S course (IDS 5717) during the Spring 2004 semester, which ended in May 2004. UCF also used the M&S BoK in that course as the basis for a portion of the course's final examination.
See Appendix 8.8 for the UCF Introduction to M&S topic sequence and the modules used.
11. During the Fall 2004 semester, ODU examined course content modules produced by GIT and evaluated for inclusion in ODU's course. Although no GIT module was used in its entirety in the ODU course, a number of ideas, explanations, and examples found in the GIT content were used to incrementally enhance the ODU course content modules.
12. ODU prepared an overview briefing describing the project and the M&S BoK for use by DMSO and submitted it to Ms. Simone Youngblood.
13. In January 2004, ODU applied updates to several of its course content modules based on experiences using the modules during the Fall 2004 offering of MSIM 601.
14. GIT used the course content modules originally developed for this project in teaching ISYE 3044 Simulation Analysis and Design.
15. GIT expanded the course content modules originally developed for this project by GIT into a sequence of 8+ lectures on modeling. Portions of this material were based on course content modules developed as part of this project provided to GIT by ODU. Portions of this expanded material have been presented as an I/ITSEC tutorial in 2004 and as components of GIT professional education courses. A link to an updated version of the modeling material is available at <http://www-static.cc.gatech.edu/people/home/Margaret/Teaching.html>.
16. GIT used the M&S BoK as the organizing basis for a series of 35 simulation lectures used for GIT professional education, although the lectures do not follow the BoK strictly.

5. Project outcome gaps

Of the five revised project objectives (see section 3.2), four were fully met (1, 2, 4, and 5). Objective 3 was only partially met. It included the expectation that "Each university was to use all of the content it had developed as well as portions of the content developed at the other universities." While it is true that each university did use content from the other universities, there was arguably less sharing and reuse of content than had been hoped for. This was not due to lack of intent to do so by the participants; rather, several other factors may have been the cause, including:

1. *Scheduling.* The universities prepared the content modules on their own schedules, and they offered their "Introduction to M&S" courses at different times (different semesters), so synchronizing the content development with the times the modules were needed was problematic.
2. *Curriculum design.* The universities' M&S curriculum differ in emphasis and sequence, with the consequence that their "Introduction to M&S" courses must address different topics.
3. *Pre-existing material.* In some cases, universities already had material developed for the topics being developed by the other universities. Understandably, instructors preferred to use their own material, developed to suit their instructional objectives, rather than the material prepared by the other universities.

6. Problems, issues, and concerns

Other than the outcome gap identified in the previous section, there are no problems, issues, or concerns.

7. Recommendations

All three universities are teaching "Introduction to M&S" courses for which there is no suitable textbook. It is recommended that a textbook be produced for those courses, generally following the jointly developed course topic sequence (Appendix 8.2).

In the envisioned textbook, chapters would be written by separate authors, experts in the topic, to include the participants in this project as well as additional persons. An editor would organize the project, select and assign topics to the authors, and ensure coherence, continuity, and coherence among the chapters.

See Appendix 8.9 for an initial working outline for such a textbook.

8. Appendices

8.1 Modeling and Simulation Body of Knowledge topical outline

1. Introduction

- 1.1 Historical overview of M&S
- 1.2 Basic M&S concepts and definitions
 - 1.2.1 Models and simulations
 - 1.2.2 M&S attributes: fidelity, resolution, and scale
 - 1.2.3 Introduction to the M&S development cycle and VV&A
- 1.3 Basic modeling methods and types
 - 1.3.1 Visual models
 - 1.3.2 Surrogates
 - 1.3.3 Physics models
 - 1.3.4 Finite element models
 - 1.3.5 Data-based models
 - 1.3.6 Aggregate models
 - 1.3.7 Conceptual models
 - 1.3.8 Hybrid models
- 1.4 M&S categories
 - 1.4.1 Types: live, virtual, constructive
 - 1.4.2 Applications: training, analysis, experimentation, and acquisition
 - 1.4.3 Domains: combat, manufacturing, medicine, engineering, commercial, others

2. M&S paradigms

- 2.1 Discrete event simulation
 - 2.1.1 DES description
 - 2.1.2 Queuing theory models for DES
 - 2.1.3 DES examples
 - 2.1.4 DES tools
- 2.2 Real-time, continuous simulation
 - 2.2.1 Definitions and concepts
 - 2.2.2 Continuous models
 - 2.2.3 Real-time simulation
 - 2.2.4 Hardware-in-the-loop, human-in-the-loop simulation
- 2.3 Visual simulation
 - 2.3.1 Special requirements
 - 2.3.2 Techniques
- 2.4 Hybrid simulations
 - 2.4.1 Definitions and concepts
 - 2.4.2 Example hybrid simulations
 - 2.4.3 Modeling issues in hybrid simulation

3. Life Cycle of a Simulation Study

- 3.1 Types and characteristics of simulation projects
 - 3.1.1 Simulation study
 - 3.1.2 Large-scale simulation software development
 - 3.1.3 Simulation exercise and event development
- 3.2 Problem formulation

- 3.2.1 Objectives, hypotheses, and scope
 - 3.2.2 Measures of merit
 - 3.2.3 Plan, schedule, and cost
 - 3.2.4 Methodology tailoring
- 3.3 Conceptual model development
 - 3.3.1 Information / data collection and analysis
 - 3.3.2 Modeling abstractions
 - 3.3.3 Level of detail, model fidelity
- 3.4 Simulation software
 - 3.4.1 Characteristics of simulation software
 - 3.4.2 World views (e.g., event oriented, process oriented, object-oriented)
 - 3.4.3 Simulation model software, frameworks
 - 3.4.4 Simulation engine, distributed simulation infrastructure
- 3.5 Verification, validation, and accreditation
 - 3.5.1 General aspects of VV&A, methods
 - 3.5.2 VV&A for U.S. DoD simulations
 - 3.5.3 Some special VV&A related issues
- 3.6 Design of experiments
 - 3.6.1 Input data analysis
 - 3.6.2 Length and number of runs
 - 3.6.3 Warm up period
- 3.7 Output analysis
 - 3.7.1 Determination of performance metrics
 - 3.7.2 Comparing alternate configurations
 - 3.7.3 Statistical methods: confidence intervals, variance reduction
 - 3.7.4 Documentation and presentation of results
- 3.8 Large-scale simulation software development
 - 3.8.1 Software project life-cycles
 - 3.8.2 Iterative software development
 - 3.8.3 Special considerations for developing simulation software
- 3.9 Simulation exercise and event development
 - 3.9.1 Introduction to exercise and events
 - 3.9.2 Simulation aspects: federation development process
 - 3.9.3 Data aspects: scenarios and databases
 - 3.9.4 Support aspects: facilities, resources and planning
- 4. Human/simulation interaction**
 - 4.1 Humans and human perception
 - 4.1.1 Sensation vs. perception
 - 4.1.2 Visual sensation and perception
 - 4.1.3 Auditory sensation and perception
 - 4.1.4 Olfactory and gustatory sensation and perception
 - 4.1.5 Haptic sensation and perception
 - 4.2 Simulation interface issues
 - 4.2.1 Varieties of simulation fidelity
 - 4.2.2 Immersion and presence
 - 4.2.3 Performance feedback

- 4.2.4 Ergonomics
- 4.3 Simulation user issues
 - 4.3.1 Modeling human cognition
 - 4.3.2 Theories of human learning
 - 4.3.3 Considering multiple users
 - 4.3.4 Adverse effects of simulation exposure
- 4.4 Interface styles and components
 - 4.4.1 Performance data generation
 - 4.4.2 The use of color
 - 4.4.3 The use and complexity of graphics
 - 4.4.4 The use of multimedia
 - 4.4.5 The use of motion
- 5. M&S interoperability**
 - 5.1 Distributed simulation
 - 5.1.1 Definitions
 - 5.1.2 SIMNET and DIS
 - 5.1.3 ALSP
 - 5.1.4 HLA
 - 5.1.5 Emerging trends (Web-enabled, XMSF)
 - 5.2 Live-virtual-constructive integration
 - 5.2.1 Concepts and motivations
 - 5.2.2 Methods, gateways, and interfaces
 - 5.2.3 Case studies
 - 5.2.4 Output analysis in LVC systems
 - 5.3 Simulation-C4ISR interoperability
 - 5.3.1 Concepts and motivation
 - 5.3.2 Methods, gateways, and interfaces
 - 5.3.3 Case studies
- 6. M&S in Department of Defense**
 - 6.1 Major DoD simulation applications
 - 6.1.1 Training
 - 6.1.2 Analysis
 - 6.1.3 Acquisition
 - 6.1.4 Experimentation
 - 6.1.5 Test and evaluation
 - 6.2 Major DoD simulations (JSIMS, JWARS, JMASS)
 - 6.2.1 Purpose of simulation within DoD
 - 6.2.2 History of DoD simulation
 - 6.2.3 Legacy simulation systems
 - 6.2.4 Emerging simulation systems
 - 6.2.5 Trends in military simulations
 - 6.2.6 Unmet military simulation needs
- 7. Special modeling methods and applications**
 - 7.1 Supply chain modeling
 - 7.2 Human behavior modeling
 - 7.3 Combat modeling

- 7.3.1 Introduction
 - 7.3.2 High resolution combat modeling
 - 7.3.3 Aggregated combat modeling
- 7.4 Decision support
- 7.5 System dynamics modeling
- 8. Future trends and special topics**
 - 8.1 Future trends in the M&S field
 - 8.2 Simulation in entertainment and games
 - 8.3 Complexity and CAS modeling
 - 8.3.1 Complexity and chaos
 - 8.3.2 Complex adaptive systems
 - 8.3.3 CAS modeling methods
 - 8.3.4 CAS modeling case studies
 - 8.4 Command and control assessment
 - 8.4.1 Introduction to NATO RTO SAS026/039
 - 8.4.2 NATO code of best practice for C2 assessment
 - 8.4.3 Examples of modeling command and control
 - 8.5 Composability
 - 8.5.1 Definitions
 - 8.5.2 Composability engineering
 - 8.5.3 Composability theory
 - 8.6 Uncertainty modeling
 - 8.6.1 Definitions and sources
 - 8.6.2 Mathematical models of uncertainty and vagueness

8.2 M&S overview course topic sequence

The course topics for a 1-semester graduate-level introductory M&S overview course are listed in the table below. Each course topic is cross referenced with the topic number(s) from the corresponding M&S BoK topic(s). The university that agreed to develop the course content for each topic is identified.

Overview course topic	BoK topic(s)	Content developer
1.1 Brief historical overview of M&S	1.1	UCF
1.2 Basic M&S concepts and definitions	1.2	ODU
1.3 Basic modeling methods and types	1.3	ODU
1.4 M&S categories	1.4	ODU
2.1 Discrete event simulation	2.1	ODU
2.2 Real-time, continuous simulation	2.2	UCF
2.3 Hybrid simulation	2.4	UCF
2.4 Visual simulation	2.3	ODU
3.1 Problem formulation	3.2	GT
3.2 Conceptual model development	3.3	GT
3.3 Simulation software	3.4	GT
3.4 Verification, validation, and accreditation	3.5	ODU
3.5 Design of experiments	3.6	ODU
3.6 Output analysis	3.7	GT
3.7 Simulation and exercise development	3.9	ODU
3.8 Document and presentation of results	3.7.4	GT
4.1 Humans and human perception	4.1	UCF
4.2 Simulation interface issues	4.2	UCF
4.3 Simulation user issues	4.3	UCF
4.4 Interface styles and components	4.4	UCF
5.1 Simulation reuse and configuration	8.5	ODU
5.2 Distributed simulation	5.1	ODU
5.3 Live-virtual-constructive integration	5.2	ODU
5.4 Simulation-C4ISR interoperability	5.3	ODU
5.5 Composability	8.5	ODU
6.1 Major DoD simulations	6.2	UCF
6.2 Using M&S for Test and Evaluation	6.1	ODU
6.3 M&S in training	6.1	UCF
7.1 Human behavior modeling	7.2	UCF
7.2 Combat modeling	7.3	ODU
7.3 Uncertainty modeling	8.6	ODU
7.4 Complexity and CAS modeling	8.3	ODU
7.5 Command and control assessment	8.4	ODU
8.1 M&S project management	3.1, 3.8, 3.9	ODU
8.2 Simulation in entertainment and games	8.2	UCF
8.3 Future trends in the M&S field	8.1	UCF

8.3 ODU course content modules developed

Course content modules developed by ODU are listed in the table below.

ODU course content module	Overview course topic(s)	BoK topic(s)	Slides
MS 1 Basic M&S Concepts & Definitions	1.2	1.2	51
MS 2 Modeling Methods	1.3	1.3	52
MS 3 M&S Categories	1.4	1.4	50
MS 4 Discrete Event Simulation	2.1	2.1	60
MS 5 Hands-on Discrete Event Simulation	2.1	2.1	45
MS 7 VV&A	3.4	3.5	60
MS 8 Distributed Simulation	5.2	5.1	86
MS 9 Interoperability and Composability	5.5	8.5	44
MS 11 Simulation Life-Cycle and Project Management	8.1	3.1, 3.8, 3.9	75
MS 13 Survey of Major Military Simulation Systems	6.1	6.2	45
MS 15 Human Computer Interaction	4.1, 4.2, 4.3, 4.4	4.1, 4.2, 4.3, 4.4	81
MS 16 Human Behavior Modeling	7.1	7.2	93
MS 17 Combat Modeling	7.2	7.3	43
MS 19 Simulation-C4ISR Interoperability	5.4	5.3	35
MS 21 Command and Control Assessment	7.5	8.4	38
MS 23 Statistics for M&S	3.5, 3.6	3.6, 3.7	85
MS 24 Modeling Uncertainty and Vagueness	7.3	8.6	50
MS 31 History of M&S	1.1	1.1	48
MS 32 Visual Simulation	2.4	2.4	25
MS 33 M&S for Training	6.3	6.1	50
MS 36 System Dynamics		7.5	~50
MS 37 Continuous and Real-time Simulation	2.2	2.2	~50

(Slide counts for modules MS 36 and MS 37 estimated.)

8.4 UCF course content modules developed

Course content modules developed by UCF are listed in the table below.

UCF course content module	Overview course topic(s)	BoK topic(s)	Slides
1.1 Historical Overview of M&S	1.1	1.1	37
2.2 Real-time Continuous Simulation	2.2	2.2	91
2.4 Hybrid-mixed Simulations	2.3	2.4	20
4.1 Human and Human Perception	4.1	4.1	118
4.2 Simulation Interface Issues	4.2	4.2	94
4.3 Simulation User Issues	4.3	4.3	173
4.4 Interface Styles and Components	4.4	4.4	144
6.1 Major DoD Simulation Applications	6.1	6.1	105
7.2 Human Behavior Modeling	7.1	7.2	27
7.4 Decision Support		7.4	35
8.1 Future Trends in the M&S Field	8.3	8.1	40
8.2 Simulation in Entertainment and Games	8.2	8.2	50

8.5 UCF multimedia segments prepared

UCF assembled 5 multimedia segments of instructional value from a variety of sources and edited and prepared them for classroom delivery. Those segments were:

1. *Careers in Simulation*. Produced by the University of Central Florida; used for recruiting of High School and College students to careers in simulation technology; 12 minutes.
2. *The Battle of 73 Easting*. Produced by IDA; makes a good case for the use of distributed simulation—SIMNET—for preparing the US Army for the largest tank battle in the first Gulf War; 10 minutes.
3. *Simulators*. Produced by the History Channel; 50 minutes.
4. *Tactical to Practical: Segment 13*. Produced by the History Channel, portion of *Simulators*; 15 minutes.
5. *The Making of Jurassic Park*. First extensive use of digital technology in a motion picture (1992-1993) and provides excellent insight into the process of converting from tradition animatronics to digital effects.

The History Channel videos may be ordered from <http://store.aetv.com/html/home/index.jhtml> and *The Making of Jurassic Park* is available as par of the *Jurassic Park* DVD set. All of these videos have made a good addition to UCF's Introduction to M&S course.

8.6 GIT course content modules developed

Course content modules developed by GIT are listed in the table below.

GIT course content module	Overview course topic(s)	BoK topic(s)	Slides
1. Simulation languages	3.3	3.4	~100
2. Output analysis	3.6	3.7	~100
3. Fundamentals of modeling	1.3	1.3	80

(Slide counts for modules 1 and 2 estimated.)

8.7 ODU M&S overview course content summary

The course topics covered in the ODU Fall 2004 offering of MSIM 601 are listed in the table below. The course topics are cross referenced with the topic number(s) from the corresponding M&S BoK topics and the ODU course content module numbers. (Non-topic class sessions and breaks in the academic calendar are omitted.)

Week of	Overview course topic	BoK topic	ODU module
8-30-2004	History of M&S	1.1	MS 31
	Basic M&S Concepts	1.2	MS 1
	Modeling Methods	1.3	MS 2
9-13-2004	M&S Categories	1.4	MS 3
	M&S Life Cycle	3.1, 3.2, 3.3, 3.4, 3.9	MS 11
9-20-2004	Discrete Event Simulation	2.1	MS 4, MS 5
9-27-2004	Design of Experiments	3.6	MS 23
	Output Analysis	3.7	MS 23
10-4-2004	Continuous/Real-Time Simulation	2.2	MS 37
	Visual Simulation	2.3	MS 32
10-18-2004	System Dynamics	7.5	MS 36
10-24-2004	Human/Simulator Interaction	4.1, 4.2, 4.3, 4.4	MS 15
11-1-2004	Human Behavioral Modeling	7.2	MS 16
11-8-2004	Verification, Validation, & Accreditation	3.5	MS 7
11-15-2004	Distributed Simulation	5.1	MS 8
	Simulation Interoperability and Composability	5.2	MS 9
11-22-2004	Combat Modeling	7.3	MS 17
	M&S in Command and Control	5.3, 8.4	MS 21
11-29-2004	M&S in Training	6.1	MS 33
	M&S in Experimentation	6.1	
	Large-Scale Simulation Examples	3.8, 6.2	MS 13
12-6-2004	Grand Challenges in Modeling & Simulation	8.1, 8.2	

8.8 UCF M&S overview course content summary

The course topics covered in the UCF Spring 2004 offering of IDS 5717 are listed in the table below. The course topics are cross referenced with the topic number(s) from the corresponding M&S BoK topics and the UCF course content module numbers. (Non-topic class sessions and breaks in the academic calendar are omitted.)

Week of	Overview course topic	BoK topic	UCF module
1-10-2004	Introduction to course		
1-17-2004	History of M&S	1.1	1.1
1-24-2004	M&S as a profession		
1-31-2004	M&S as an academic discipline		
2-7-2004	Simulation for entertainment	8.2	8.2
2-14-2004	Simulation for military applications	6.1	6.1
2-21-2004	Continuous (human-in-the-loop) simulation	2.2	2.2
2-28-2004	Discrete event simulation	2.2	2.2
3-7-2004	Simulation for training	6.1.1	
3-21-2004	Medical simulation		
3-28-2004	Virtual environments	2.3	
4-4-2004	Simulation for disaster response		

8.9 Initial outline of recommended textbook

Part 1 – Introduction

1. History of M&S
2. Basic M&S concepts and definitions
3. Survey of modeling methods and simulation categories

Part 2 – Fundamental modeling paradigms

4. Discrete event simulation
5. Mathematical modeling of physical systems
6. Continuous and real-time simulation
7. Visualization, visual simulation, and virtual environments
8. Distributed simulation and interoperability
9. System dynamics modeling
10. Agent-based modeling

Part 3 – Humans and simulations

11. Human-computer interaction in simulation
12. Simulating human behavior
13. Modeling human decision making

Part 4 – Special applications and modeling methods

14. M&S applications in the U.S. Department of Defense
15. Combat modeling and simulation
16. Medical modeling and simulation
17. Modeling and simulation in entertainment
18. Modeling complex adaptive systems
19. Modeling uncertainty and vagueness

Part 5 – M&S projects

20. Experimental design and data analysis for simulation
21. Verification, validation, and accreditation
22. M&S life-cycles, project types, and project management
23. Simulation software tools and languages
24. M&S composability

Part 6 – Future M&S

25. Emerging M&S applications
26. Grand challenges in M&S

8.10 Project meeting chronology

Three face-to-face meetings were held by the universities during the project, as follows:

1. November 4-5 2003 at ODU
2. March 18-19 2004 at UCF
3. May 24-25 2004 at GIT

8.11 Acronyms and abbreviations

BoK	Body of Knowledge
DMSO	Defense Modeling and Simulation Office
GIT	Georgia Institute of Technology
I/ITSEC	Interservice/Industry Training, Simulation, and Education Conference
M&S	Modeling and Simulation
ODU	Old Dominion University
UCF	University of Central Florida

8.12 Project overview briefing

This appendix provided as separate document.

8.13 Author and acknowledgements

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M&S Body of Knowledge & Course Content Development

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 - University of Central Florida (UCF)
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Project Description and Status

M&S “Body of Knowledge” (BoK)

- What is an M&S BoK?
 - Definition of domain of M&S
 - Organized list of definitions, concepts, methods, frameworks, techniques, theories, tools, practices, standards, ...
 - Central core of M&S knowledge
- Why develop an M&S BoK?
 - Basis for industry communication
 - Content for M&S education
 - Domain for M&S professional certification

BoK development efforts

- This project: University M&S BoK
 - Developed by ODU, GIT, & UCF
 - Goal: define content for M&S education
 - Sponsored by DMSO
- Other BoK efforts
 - SimSummit M&S BoK
 - Society for Computer Simulation M&S BoK
- Common aspects of these efforts
 - Develop BoK as topical outline
 - Work toward community consensus on topics

Project activities to date

- Develop University BoK
 - Topic outline developed by ODU, GIT, & UCF
 - Discussed at three face-to-face meetings
 - Outline currently being externally reviewed in limited circulation
- Prepare course content for BoK
 - ODU developed: 19 topics, 1020 slides
 - GIT and UCF developed: similar

Project activities planned

- Share content developed for BoK
 - ODU: 3 topics sent to GIT, UCF
 - GIT & UCF: similar planned
- Test content in university courses
 - ODU: MSIM 601 Intro to M&S, Fall 2004
 - GIT and UCF: similar
- Circulate outline widely for external review
- Coordinate with other BoK efforts

University BoK Outline

University Bok

1. Introduction
 - 1.1 Historical overview of M&S
 - 1.2 Basic M&S concepts and definitions
 - 1.2.1 Models and simulations
 - 1.2.2 M&S attributes: fidelity, resolution, and scale
 - 1.2.3 Introduction to the M&S development cycle and VV&A
 - 1.3 Basic modeling methods and applications
 - 1.3.1 Visual models
 - 1.3.2 Surrogates
 - 1.3.3 Physics models
 - 1.3.4 Finite element models
 - 1.3.5 Data-based models
 - 1.3.6 Aggregate models
 - 1.3.7 Conceptual models
 - 1.3.8 Hybrid models
 - 1.4 M&S categories
 - 1.4.1 Types: live, virtual, constructive
 - 1.4.2 Applications: training, analysis, experimentation, and acquisition
 - 1.4.3 Domains: combat, manufacturing, medicine, engineering, commercial, others
2. M&S paradigms
 - 2.1 Discrete event simulation
 - 2.1.1 DES description
 - 2.1.2 Queuing theory models for DES
 - 2.1.3 DES examples
 - 2.1.4 DES tools

- 2.2 Real-time, continuous simulation
 - 2.2.1 Definitions and concepts
 - 2.2.2 Continuous models
 - 2.2.3 Real-time simulation
 - 2.2.4 Hardware-in-the-loop, human-in-the-loop simulation
- 2.3 Visual simulation
 - 2.3.1 Special requirements
 - 2.3.2 Techniques
- 2.4 Hybrid/mixed simulations
 - 2.4.1 Definitions and concepts
 - 2.4.2 Example hybrid simulation
 - 2.4.3 Modeling issues in hybrid simulation
- 3. Life Cycle of a Simulation Study
 - 3.1 Types and characteristics of simulation projects
 - 3.1.1 Simulation study
 - 3.1.2 Large-scale simulation software development
 - 3.1.3 Simulation exercise and event development
 - 3.2 Problem formulation
 - 3.2.1 Objectives, hypotheses, and scope
 - 3.2.2 Measure of merit
 - 3.2.3 Plan, schedule, and cost
 - 3.2.4 Methodology tailoring
 - 3.3 Conceptual model development
 - 3.3.1 Information/data collection and analysis
 - 3.3.2 Modeling abstractions
 - 3.3.3 Level of detail, model fidelity

- 3.4 Simulation software
 - 3.4.1 Characteristics of simulation software
 - 3.4.2 World views (e.g., event oriented, process oriented, object oriented)
 - 3.4.3 Simulation model software, frameworks
 - 3.4.4 Simulation engine, distributed simulation infrastructure
- 3.5 Verification, validation, and accreditation
 - 3.5.1 General aspects of VV&A, methods
 - 3.5.2 VV&A for U.S. DoD simulations
 - 3.5.3 Some special VV&A related issues
- 3.6 Design of experiments
 - 3.6.1 Input data analysis
 - 3.6.2 Length and number of runs
 - 3.6.3 Warm up period
- 3.7 Output analysis
 - 3.7.1 Determination of performance metrics
 - 3.7.2 Comparing alternate configurations
 - 3.7.3 Statistical methods: confidence intervals, variance reduction
 - 3.7.4 Documentation and presentation results
- 3.8 Large-scale simulation software development
 - 3.8.1 Software project life-cycles
 - 3.8.2 Iterative software development
 - 3.8.3 Special considerations for developing simulation software
- 3.9 Simulation exercise and event development
 - 3.9.1 Introduction to exercises and events
 - 3.9.2 Simulation aspects: federation development process
 - 3.9.3 Data aspects: scenarios and databases
 - 3.9.4 Support aspects: facilities, resources, and planning

- 4. Human/simulation interaction
 - 4.1 Humans and human perception
 - 4.1.1 Sensation vs. perception
 - 4.1.2 Visual sensation and perception
 - 4.1.3 Auditory sensation and perception
 - 4.1.4 Olfactory and gustatory sensation and perception
 - 4.1.5 Haptic sensation and perception
 - 4.2 Simulation interface issues
 - 4.2.1 Varieties of simulation fidelity
 - 4.2.2 Immersion and presence
 - 4.2.3 Performance feedback
 - 4.2.4 Ergonomics
 - 4.3 Simulation user issues
 - 4.3.1 Modeling human cognition
 - 4.3.2 Theories of human learning
 - 4.3.3 Considering multiple users
 - 4.3.4 Adverse effects of simulation exposure
 - 4.4 Interface styles and components
 - 4.4.1 Performance data generation
 - 4.4.2 The use of color
 - 4.4.3 The use and complexity of graphics
 - 4.4.4 The use of multimedia
 - 4.4.5 The use of motion
- 5. M&S interoperability
 - 5.1 Distributed simulation
 - 5.1.1 Definitions
 - 5.1.2 SIMNET and DIS
 - 5.1.3 ALSP
 - 5.1.4 HLA
 - 5.1.5 Emerging trends (web-enabled, XMSF)

- 5.2 Live-virtual-constructive integration
 - 5.2.1 Concepts and motivations
 - 5.2.2 Methods, gateways, and interfaces
 - 5.2.3 Case studies
 - 5.2.4 Output analysis in LVC systems
- 5.3 Simulation-C4ISR interoperability
 - 5.3.1 Concepts and motivation
 - 5.3.2 Methods, gateways, and interfaces
 - 5.3.3 Case studies
- 6. M&S in Department of Defense
 - 6.1 Major DoD simulation applications
 - 6.1.1 Training
 - 6.1.2 Analysis
 - 6.1.3 Acquisition
 - 6.1.4 Experimentation
 - 6.1.5 Test and evaluation
 - 6.2 Major DoD simulations
 - 6.2.1 Purposes of simulation within DoD
 - 6.2.2 History of DoD simulation
 - 6.2.3 Legacy simulation systems
 - 6.2.4 Emerging simulation systems
 - 6.2.5 Trends in military simulation
 - 6.2.6 Unmet military simulation needs

- 7. Special modeling methods and applications
 - 7.1 Supply chain modeling
 - 7.2 Human behavior modeling
 - 7.3 Combat modeling
 - 7.3.1 Introduction
 - 7.3.2 High resolution combat modeling
 - 7.3.3 Aggregated combat modeling
 - 7.4 Decision support
 - 7.5 System dynamics modeling
- 8. Future trends and special topics
 - 8.1 Future trends in the M&S field
 - 8.2 Simulation in entertainment and games
 - 8.3 Complexity and CAS modeling
 - 8.3.1 Complexity and chaos
 - 8.3.2 Complex adaptive systems
 - 8.3.3 CAS modeling methods
 - 8.3.4 CAS modeling
 - 8.4 Command and control assessment
 - 8.4.1 Introduction to NATO RTO
 - 8.4.2 NATO code of best practice for C2 assessment
 - 8.4.3 Examples of modeling command and control
 - 8.5 Composability
 - 8.5.1 Definitions
 - 8.5.2 Composability engineering
 - 8.5.3 Composability theory
 - 8.6 Uncertainty modeling
 - 8.6.1 Definitions and sources
 - 8.6.2 Mathematical models of uncertainty and vagueness